Methodology Development

Development of Damage Function for Stratospheric Ozone Layer Depletion

A Tool Towards the Improvement of the Quality of Life Cycle Impact Assessment

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Abstract. The purpose of our study was to develop damage functions due to ozone layer depletion, that related the emission of ozone depleting substances (ODS) to the damage of category endpoints. The ozone layer depletion causes many types of damage such as skin cancer, cataract, adverse effect to crop and plant growth. We assessed the increase of skin cancer incidence risk. The damage function have been developed with connecting the main processes on ozone depletion, emission of ODS, increase of tropospheric ODS, increase of stratospheric ODS, change of total ozone, change of B region ultra-violet (UV-B) at the surface, and the increase of skin cancer incidence. As the result, we could introduce damage functions of melanoma and non-melanoma skin cancer incidence for 13 species of ODSs and damage factors based on the disability-adjusted life years (DALYs). We also compared the DALYs value with the damage factors of Eco-indicator 99 (egalitarian and hierarchic value), and it was found that our result was several ten times as small except methyl bromide. Furthermore, a case study for refrigerator was performed and it showed that shifting to less ozone depleting substances reduced the risk of skin cancer incidence to one-fourteenth in DALYs.

Keywords: B region ultra violet; damage function; disability-adjusted life years; LCIA; life cycle impact assessment; non-melanoma skin cancer; ozone depleting substance; ozone depletion; skin cancer; melanoma

Abbreviations: ODSs-Ozone Depleting Substances; CFCs-Chlorofluorocarbons; DALYs-Disability-adjusted Life Years; HCFCs-Hydrochlorofluorocarbons; ODP-Ozone Depletion Potential; TCL-Tropospheric Chlorine Loading; EESC-Equivalent Effective Stratospheric Chlorine; UV-B-B Region Ultra violet

Introduction

According to Goedkoop and Spriensma (2000a), the process of weighting in LCIA can be divided into two types, theme-oriented approach and damage-oriented approach. The former one relates the result of midpoint level such as increased radiative forcing by characterization with the single index. The Eco-indicator 95 (Goedkoop, 1995) and EDIP (Hauschild, 1996) are belonging to the theme-oriented approach. The latter one evaluates the damage of an endpoint level to estimate the single index like the increased heat stress (**Fig. 1**). The process between the cause and the damage depends on the category endpoints. EPS (Steen, 1996), ExternE (ExternE, 1997), Eco-indicator'99 belong to the damage-oriented approach. The theme-oriented approach is simple, because the quantitatively calculated results in characterization can be restricted for the endpoint approach. However the directly estimated single index from the characterization result is comparatively unclear, because there is no information related with actual effect like the damage of category endpoints. The damage-oriented approach can make it clear what types of category endpoints have been considered, but the methodology is not matured in the following points, (1) all types of endpoints have not been considered, (2) the uncertainty of the damage estimations are not small in some cases. Both approaches have merits and demerits. Consequently, the further development of both methodologies should be recommended to improve the level of impact assessment.

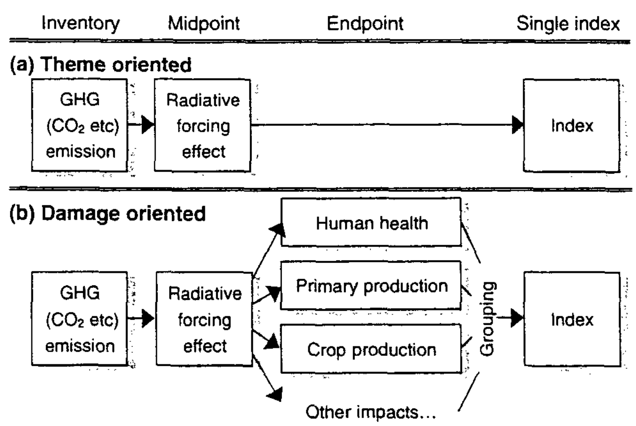

Fig. 1: The difference of the procedures of theme-oriented approach and damage-oriented approach

In Japan, several methodologies have been proposed in several years (Matsuno et al., 1998), (Nagata et al., 1996), (Yasui, 1998), (Itsubo et al., 1998; 1999). All types of these methods belong to the theme-oriented approach. Itsubo et al. (2000) compared these methods to characterize them with a case study in the common inventory table. According to this study, the results of weighting across the impact categories were quite different even using the same inventory. It was difficult to recommend what was the reasonable result because of the lack of transparency in the methodologies. Clarifying the endpoint and the damage quantification in the damage-oriented approach can improve the transparency of the estimation flow for users. Currently, no damage-oriented approach exists in Japan. To develop these methodologies, we have to assess the actual damage by the load of environmental affective substances with the basis of weighting among respective impacts. We defined this type of estimation as damage functions.

Fig. 2 describes the scope of damage function. The route of cause-effect of environmental problem is quite dependent on category endpoints. Therefore, we have to consider damage functions for respective category endpoints.

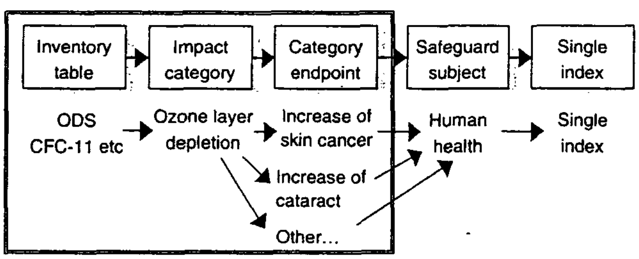

Fig. 2: The scope of damage functions

Ozone depletion is one of the serious global environmental problems. Artificially emitted halocarbons, such as chlorofluorocarbons, destroy the stratospheric ozone. These substances are called ODSs. The stratospheric ozone depletion will strongly affect the global climatic system. Simultaneously, an increase in the irradiation of ultraviolet radiation rays at the surface, significantly UV-B, and increased UV-B will lead to various harmful impacts on human health, ecosystems and materials.

The ODP (Solomon et al., 1992a and 1992b) has been used in most of the previous LCIA studies for the stratospheric ozone depletion problem. The ODP is relative value, dividing the ozone destroying ability of specific ODS by that of CFC-11. The ODP can be a characterization factor that specifies the midpoint level assessment. However, the ODP does not have any information on the actual impacts on receptors by ozone depletion. Hence, the ODP is not a sufficient indicator in the damage-oriented approach.

To improve such circumstances, the Working Group of Impact Assessment has allocated a research program to develop damage functions for the stratospheric ozone layer depletion that evaluate the quantitative impacts of ozone depletion on the receptors. The Damage Function Sub-Committee, composed of the expert for several environmental problems, has been founded to establish and provide the damage functions to develop the damage-oriented methodology in Japan. The Working Group of Impact Assessment is a part of the National LCA Project in Japan that has been implemented by the New Energy and Industrial Technology Development Organization (NEDO). This report shows the result of damage function estimation for ozone layer depletion, as the result in the first year of the project.

Although the impacts of ozone depletion include many receptors, we focused our aim on the human health impacts as a first step. The purpose of our study was to estimate the quantitative relationship of ODS emission to the harmful impacts on human health, especially on skin cancers.

1 Method

1.1 Methodology overview

Human health impacts of the stratospheric ozone depletion occur through several processes, 1: ODS emission at the surface, 2: ODS increase in the troposphere, 3: ODS increase in the stratosphere, 4: ozone depletion in the stratosphere, 5: UV-B radiation increase at the surface, and 6: health risk increase. There are two important time lags between process 1-2, and process 5-6. For process 1-2, it generally takes three years that an air mass in the troposphere flows into the stratosphere (WMO, 1994), thus we set the time lag between process 1-2 as 3 [yr]. On the other hand, it was very difficult to determine the time lag between process 5-6. Skin cancer may occur with long period exposure to UV-B, perhaps after several decades. However, the relationship of skin cancer incidence to UV-B exposure was not clear in amount and time. Therefore, we simplified our estimation to evaluate the future risk connecting the present data on UV-B amount and skin cancer incidence.

Damage function of stratospheric ozone depletion was calculated to quantitatively connect these processes based on the present knowledge. It was assumed that ODS concentration in the troposphere and the stratosphere was homogeneous. It is known, however, that ozone concentration in the stratosphere varies for latitudinal direction (JMA, 1998). Therefore, latitudinal distribution of the stratospheric ozone should be considered. Then, we set latitude bands for an initial damage function estimation. Each band had 10 degrees width. The range of latitude bands was between 60N and 60S due to the satellite data availability on ozone concentration. Additionally, we used the total ozone, all of the ozone in the atmospheric column, instead of the actual ozone concentration in the stratosphere mainly due to data availability. It seemed to be reasonable to use total ozone, because approximately 90% of the total ozone existed in the stratosphere (WMO, 1994).

Damage function estimation consisted of three steps, 1: estimation of damage function for respective latitude band, 2: estimation of latitudinal distribution of population and skin color ratio, and 3: estimation of global merged damage function. The estimation flow is shown in **Fig. 3**.

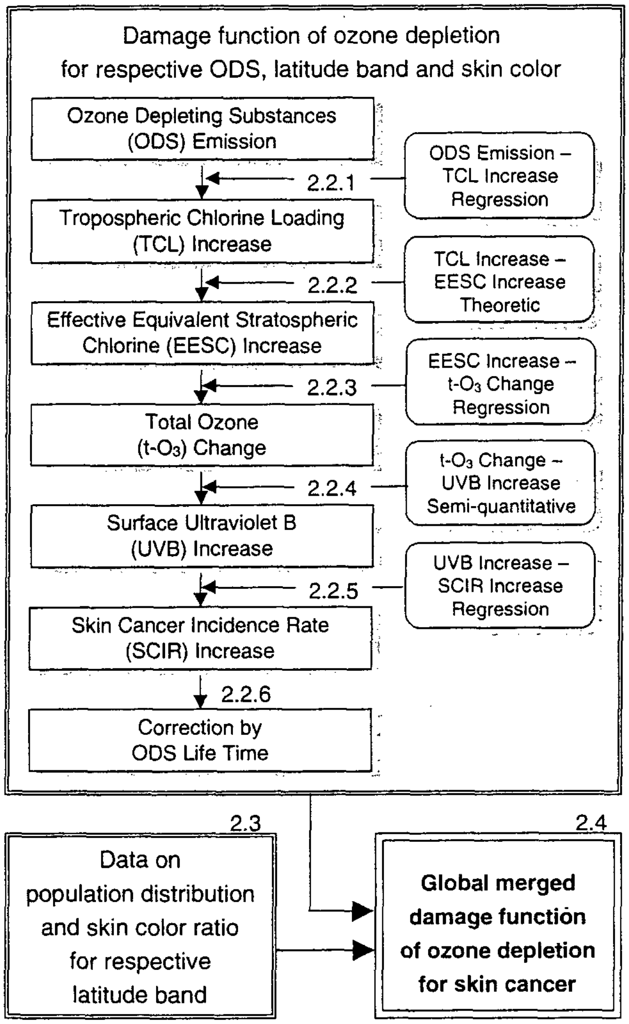

Fig. 3: Estimation flow of the damage function of ozone depletion for skin cancer. Specified number indicates the corresponding section in this report

1.2 Damage function for respective latitude band

1.2.1 TCL increase due to ODS emission

We estimated the relationship between ODS emission at the surface and ODS level in the troposphere. The ozone depletion is caused by chlorine (Cl) and bromine (Br) contained in ODS; accordingly, ODS concentration should be represented as a Cl and Br related indicator. We used total chlorine loading (TCL) defined by Daniel et al. (1995).

$$TCL\ [pptv] = \Sigma \{ nCl(X) + nBr(X)\ \alpha \}\ C(X)_{trop} \qquad (1)$$

Here, X means specific ODS, nCl and nBr are number of Cl and Br atom in a molecule of X respectively, α is Br/Cl ratio on ozone destroying ability, and $C(X)_{trop}$ is concentration of X in the troposphere [pptv]. $\alpha = 40$ based on the existing references (Daniel et al., 1995; WMO, 1994).

Some data was available on global emission inventory and concentration in the troposphere. However, these data did not cover all of major ODSs except CFC-11, CFC-12 and so forth. Past global annual CFC-11 emission load was obtained from Kaye et al. (1994). The tropospheric CFC-11 level was obtained from monitoring data (NOAH, 1998). The level at the beginning of each year was converted into TCL. The annual difference of TCL was considered as TCL change, dTCL(CFC-11)/dt [pptv/yr]. Using data after 1988, when CFC-11 emission amount had turned to decrease, a linear regression model was introduced with dTCL(CFC-11)/dt as the objective variable and global CFC-11 annual emission as the explanatory variable. The slope of the model 0.081 [pptv/kt] in **Fig. 4** was set as the coefficient that gave TCL increase to unit emission of CFC-11. It was assumed that a similar coefficient of X could be derived by compensating the coefficient of CFC-11 with the molecular weight and the number of Cl and/or Br atoms in a molecule of X, then we introduced following equations.

$$dTCL(X)/dt\ [pptv/yr] = A\ dTCL(CFC\text{-}11)/dt \qquad (2)$$

$$A = \{\{nCl(X) + nBr(X)\ \alpha\}/mw(X)\}/\{\{nCl(CFC\text{-}11) + nBr(CFC\text{-}11)\ \alpha\}/mw(CFC\text{-}11)\}$$

$$= \{\{nCl(X) + nBr(X)\ \alpha\}/mw(X)\}/\{3/137.4\} \qquad (3)$$

Here, mw(X) is the molecular weight of X.

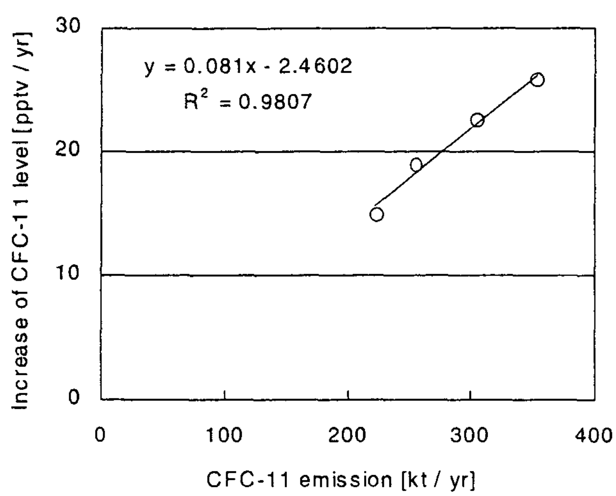

Fig. 4: Relationship of CFC-11 level increase to CFC-11 emission

1.2.2 EESC increase due to TCL increase

ODS in the troposphere is transported to the stratosphere by the atmospheric general circulation system. Only free Cl and Br atoms separated from ODS destroy ozone in the stratosphere. Separativeness of ODS depends on its species, and ODS concentration in the stratosphere should be estimated as effectiveness of ozone depletion. Free Cl and Br concentration in the stratosphere was expressed as Equivalent Effective Stratospheric Chlorine (EESC) by Daniel et al. (1995). EESC is free Cl equivalent concentration,

$$EESC_t\ [pptv] = \Sigma\ TCL(X)_{t\text{-}3}\ FC(X) \qquad (4)$$

Here, t is the specific year and FC(X) is Cl and/or Br atoms releasing ratio of X in the stratosphere. It approximately

takes three years that an air mass in the troposphere flows into the stratosphere (WMO, 1994), so that we set the target year of EESC was three years later than that of TCL. FC(X) is defined by Daniel et al. (1995),

$$FC(X) = \{ \mu_{entry}(X) - \mu_{\Phi,z}(X) \} / \mu_{entry}(X) \quad (5)$$

Here, $\mu_{entry}(X)$ [pptv] is the concentration of X that flows into the stratosphere, $\mu_{\Phi,z}(X)$ [pptv] is concentration of X at latitude Φ and altitude z. FC(X) ranges from 0 to 1 and FC(X) = 1 means that X releases all Cl and/or Br atoms in the stratosphere.

Global and vertical distribution of X should be known if FC(X) was strictly calculated, although a simple method was taken in this study. We used the relative value of FC(X) to FC(CFC-11) showed in Daniel et al. (1995). FC(CFC-11) was calculated with existing CFC-11 vertical profile data (EAJ, 1998) and eq. 6 and 7 (Daniel et al., 1995). Then FC(X) was calculated as the product of the FC(X)/FC(CFC-11) ratio and the FC(CFC-11).

$$FC(CFC\text{-}11) = \{C(CFC\text{-}11)_{tpause} - \mu_{\Phi,z}(CFC\text{-}11)\} / C(CFC\text{-}11)_{tpause} \quad (6)$$

$$\mu_{\Phi,z}(CFC\text{-}11) = \Sigma P_z \, C(CFC\text{-}11)_Z / \Sigma P_z \quad (7)$$

Here, $C(CFC\text{-}11)_{tpause}$ is CFC-11 level at the tropopause, P_z [hPa] is air pressure at altitude z.

Based on eq. 4, dEESC(X)/dt [pptv/yr] corresponding to emission of X at the surface was determined. Sum of EESC increase for all target ODSs, namely ΣdEESC(X)/dt, was calculated and added to the EESC in 1998. We set the base year was 1995, and, as mentioned above, there were three years of time lag, so that the TCL in 1995 corresponded to the EESC in 1998. Hence, ΣdEESC(X)/dt was added to the EESC in 1998.

The estimated regression coefficients of TCL and EESC increase due to emission of X and FC(X) values are shown in **Table 1**.

Table 1: Regression coefficients for TCL and EESC to ODSs emission

ODSs		dTCL(X)/dt coefficients	FC(X)	dEESC(X)/dt coefficients
CFCs	CFC-11	0.081	0.59	0.048
	CFC-12	0.061	0.35	0.022
	CFC-113	0.059	0.44	0.026
Halons	Halon-1211	0.920	0.65	0.597
	Halon-1301	0.996	0.47	0.470
Carbon Tetrachloride		0.096	0.63	0.060
1,1,1-Trichloroethane		0.083	0.64	0.053
HCFCs	HCFC-22	0.043	0.21	0.009
	HCFC-123	0.049	0.65	0.032
	HCFC-124	0.027	0.31	0.008
	HCFC-141b	0.063	0.42	0.027
	HCFC-142b	0.037	0.21	0.008
Methyl Bromide		1.563	0.64	0.996

*dEESC(X)/dt coefficient = FC(X) dTCL(X)/dt coefficient

*dEESC(X)/dt [pptv] = dEESC(X)/dt coeffient Emission(X) [kt]

1.2.3 Total ozone change due to EESC increase

It is known that total ozone amount and degree of ozone depletion have much spatial and seasonal fluctuations. And it is also known that heterogeneous system such as the solid-liquid phase reaction in the polar stratospheric clouds has a large contribution to the drastic ozone depletion.

To handle the complex ozone depletion mechanism simply, we estimated the relationship between the past EESC trend and the total ozone trend. The EESC trend was due to WMO (1994) and the total ozone trend was due to Mac Peter and Beach (1996).

The period of the total ozone data was Nov. 1978-Apr. 1993 as observed by a total ozone mapping spectrometer (TOMS) with the artificial satellite Nimbus-7. Using the original data, monthly 5 degrees width of latitude band data, we first calculated 10 degrees width of averaged total ozone. The geographical area of each 5 degrees width band was used as the average weight. Next, the seasonal average was calculated. Seasonal division was Dec.-Feb., Mar.-May, Jun.-Aug. and Sep.-Nov. It was assumed that the EESC value in certain season was homogeneous in the respective latitude band. Finally, linear regression models were introduced that gave seasonal total ozone amount in respective 10 degrees width of the latitude band as a function of the EESC. **Table 2** shows the models and **Fig. 5**

Table 2: Regression models of total ozone to EESC

Lat.	Dec.-Feb.		Mar.-May		Jun.-Aug.		Sep.-Nov.	
	a	b	a	b	a	b	a	b
50-60N	-0.022	430.3	-0.026	466.6	-0.007	360.2	-0.012	345.6
40-50N	-0.028	419.7	-0.023	431.7	-0.005	342.1	-0.010	325.7
30-40N	-0.020	351.0	-0.014	365.4	-0.004	314.2	-0.007	297.6
20-30N	-0.010	286.2	-0.004	301.7	-0.002	294.1	-0.005	282.7
10-20N	-0.004	256.5	-0.001	269.6	-0.002	284.2	-0.003	274.0
0-10N	0.002	244.7	-0.000	260.1	-0.003	277.8	-0.001	268.5
0-10S	0.002	252.0	-0.000	259.6	-0.005	272.2	-0.003	272.1
10-20S	-0.001	267.9	-0.003	265.5	-0.008	278.9	-0.004	283.2
20-30S	-0.005	284.3	-0.005	277.1	-0.008	295.4	-0.005	304.1
30-40S	-0.010	311.3	-0.008	297.9	-0.012	336.3	-0.008	342.6
40-50S	-0.016	343.8	-0.011	320.0	-0.015	365.4	-0.014	382.3
50-60S	-0.021	376.5	-0.014	338.5	-0.019	374.4	-0.031	436.4

*Total ozone amount [m atm-cm] = a EESC [pptv] + b

*Data period: Nov.,1978- Apr.,1993

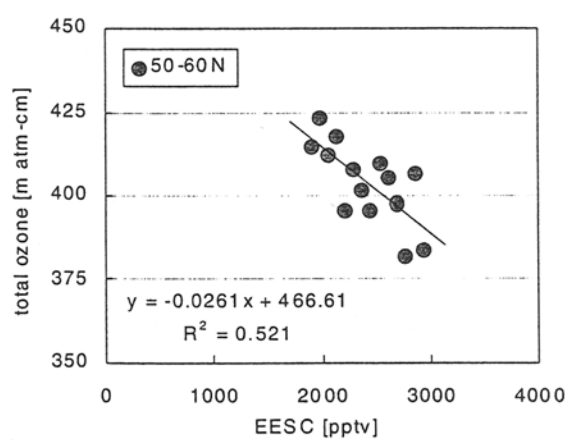

Fig. 5: Example of the relationship between EESC and total ozone (lat50-60N, Mar.-May). The effect of volcano and quasi-biennial oscillation was not excluded.

shows an example of the relationship between EESC and total ozone. Target latitude bands were set between lat.60N and lat.60S. Other regions were excluded because of the incompleteness of the satellite data where polar nights occurred.

1.2.4 UV-B change at the surface due to total ozone change

The relationship between total ozone amount and UV-B intensity at the surface was regressed with the observation data of total ozone and UV-B (JMA, 1998). Averaged absorption cross-sections for a molecule of ozone was calculated for 290-300 nm, 300-310 nm and 310-320 nm wavelength band with the cross-sections for respective wavelength (Houghton, 1986). Then τ_{O3}, optical thickness of ozone to UV-B was calculated using the total ozone data (Mac Peter and Beach, 1996). The wavelength band 280-290 nm was excluded because of hardly reaching at the surface (JMA, 1998).

τ_{O3} corresponds to the reduction ability of direct solar radiation. However, UV-B is also scattered/absorbed by other gases and aerosols. Furthermore, UV-B radiation at the surface consists of direct and scattered radiation. Hence, it was impossible to correctly calculate the intensity of UV-B at the surface only based on the τ_{O3}. Although the intensity of UV-B could be calculated according to the radiation theory, a more simple regression method was examined and used in this study to lead the relationship between change of total ozone amount and the change of UV-B amount at the surface.

Firstl of all, data of total ozone amount, UV-B radiation intensity at the surface and solar zenith angle ZA at the same time were extracted from existing observations (JMA, 1998) in daytime at fine weather. Next, UV-B intensity at the upper end of the atmosphere was theoretically calculated for each wavelength band with solar constant (Houghton, 1986) and compensating it with the distance between the sun and the earth (Aida, 1982). It was assumed that reduction of UV-B was approximately represented by the attenuation equation of direct radiation. Then apparent optical thickness τ was calculated with theoretical UV-B intensity at the top of the atmosphere and observed UV-B intensity at the surface. Finally, the correlation between theoretical τ_{O3} and empirical τ was modeled for the respective wavelength band (Fig. 6). UV-B

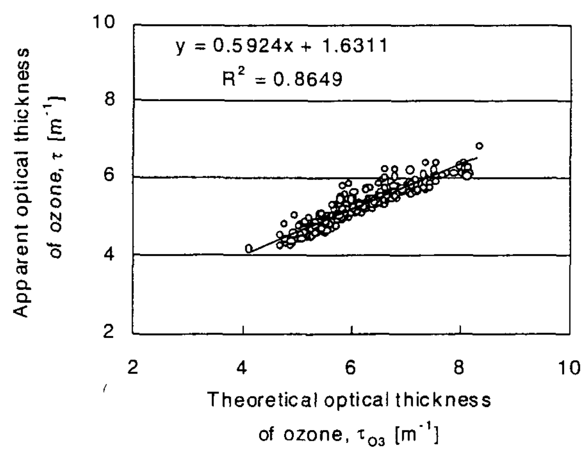

Fig. 6: Relationship between theoretical and apparent optical thickness of ozone in the wavelength band 290-300nm.

intensity at the surface could be calculated by the model at any total ozone amount and ZA. Further, annual UV-B amount at the surface in the center of the respective latitude band was calculated. Empirical τ was to avoid the effect of the transfer distance in the atmosphere, = 1/cosZA.

1.2.5 SCIR change due to UV-B change

Some existing data was found related to incidence rate and/or mortality of cancers (Altmeyer et al., 1997; Aoki et al., 1992; Ferlay et al., 1997). Ferlay et al. (1997) shows incidence rate of cancers in the major part of the world, approximately 50 countries, compiled by the International Agency for Research on Cancer (IARC)/WHO. Though the statistical year is different among the various countries, it generally contains averaged data from 1988 to 1992. Skin cancer in the database is divided into melanoma and non-melanoma. There are two types of skin cancer incidence rate (SCIR), actual incidence rates and age-standardized incidence rates (ASR). ASR was used in this study.

A polynomial function of latitude that gave annual surface UV-B in the base year, here 1998, based on the previously estimated annual UV-B at the center of the respective latitude band. Annual surface UV-B at the center of each country in the database was calculated with the polynomial function. Then, the relationship between the annual surface UV-B and the SCIR was linearly modeled. The SCIR-UV-B model was introduced for respective skin color, white, yellow and black. However, these models could only be introduced in some parts of the Northern Hemisphere. Hence, we adopted these models to exclude ranges of the Northern Hemisphere as an extrapolation, and also to the whole of the Southern Hemisphere. SCIR change due to ODS emission was calculated by the following steps. Firstly, estimated annual surface UV-B after ODS emission was substituted into the models to obtain new SCIR. Next, the subtraction between new SCIR and the SCIR in the base year was calculated. And the difference was defined as initial SCIR increase, SCIR increase when the effect of newly emitted ODS appeared.

1.2.6 Damage function correction by ODS life time

ODS has its life-time in the atmosphere and this factor should be considered to estimate total impact due to ODS emission. The initial SCIR increase was compensated with the life-time of the respective ODS. We assumed that the concentration of specific ODS emitted in specific year was described as an exponential curve.

$$C = C_0 e^{-kt} \quad (8)$$

Here, C_0 is ODS concentration in the initial year, k is a coefficient that depends on the ODS life-time and t is time [yr] (t = 0 at the initial year). For standardization, C_0 was set at 1 and it was assumed that the end of life-time of ODS was when C was 1/1000 of C_0. The k value for respective ODS was estimated with the existing data on life-times (WMO, 1994). Then, eq. 8 was integrated for t from 0 to the life-time. The integration value was defined as a correction coefficient that compensated the initial SCIR increase to the total impact due to ODS emission.

The product of the initial SCIR increase and the correction coefficient was calculated for all of the target ODSs when emission load changed. We confirmed the linearity (e.g. see **Fig. 7**), and the slope of SCIR increase to emission amount of specific ODS was defined as the damage function of ozone depletion on skin cancer for the respective latitude band. **Table 3** shows an example. Unit of the damage function was [incidence 100,000persons^{-1} kt^{-1}]. It meant total increase of new skin cancer incidence to 100,000 persons according to specific ODS emitted in a year and while it exited in the atmosphere [kt], with respective skin cancer type, with specific skin color, and in specific latitude band.

In fact, skin cancer may occur due to several decades of UV-B exposure, therefore, it seems to be difficult to estimate the impact of ODS emission to skin cancer incidence simply. We, however, suggest that total impacts of ODS emitted that specific year should be considered as impacts of the same year.

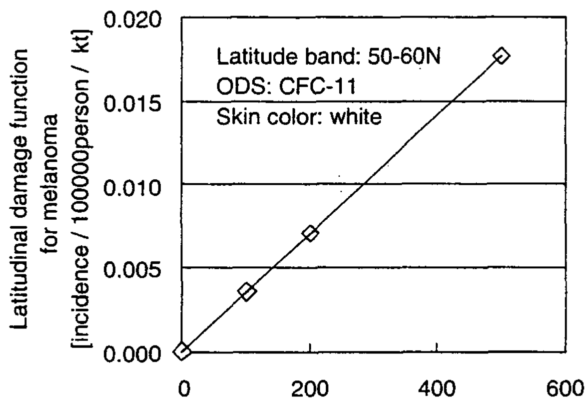

Fig. 7: Linearity confirmation of the damage function for melanoma due to CFC-11 emission

Table 3: Latitudinal damage function of ozone depletion for skin cancer of CFC-11

Lat.	Melanoma			Non-melanoma		
	white	yellow	black	white	yellow	black
50-60N	3.53E-5	2.81E-6	1.55E-7	1.18E-4	0	0
40-50N	5.46E-5	4.36E-6	2.41E-7	1.83E-4	0	2.40E-5
30-40N	6.25E-5	4.98E-6	2.75E-7	2.09E-4	3.99E-5	2.74E-5
20-30N	4.36E-5	3.48E-6	1.92E-7	1.46E-4	2.79E-5	1.91E-5
10-20N	2.61E-5	2.09E-6	1.15E-7	8.75E-5	1.67E-5	1.15E-5
0-10N	5.19E-6	4.14E-7	2.28E-8	1.74E-5	3.31E-6	2.28E-6
0-10S	1.42E-5	1.13E-6	6.24E-8	4.74E-5	9.05E-6	6.22E-6
10-20S	4.23E-5	3.37E-6	1.86E-7	1.41E-4	2.70E-5	1.86E-5
20-30S	5.10E-5	4.07E-6	2.25E-7	1.71E-4	3.26E-5	2.24E-5
30-40S	6.88E-5	5.48E-6	3.03E-7	2.30E-4	4.39E-5	3.02E-5
40-50S	7.33E-5	5.85E-6	3.23E-7	2.45E-4	4.68E-5	3.22E-5
50-60S	7.88E-5	6.28E-6	3.47E-7	2.64E-4	0	0

*Ozone depleting substance: CFC-11
*Skin cancer type: melanoma and non-melanoma skin cancer
*Skin color type: white, yellow and black
*0 value is to avoid negative extrapolation of SCIR

1.3 Latitudinal distribution of population and skin color ratio

Population distribution and component of skin color, white, yellow and black in respective latitude band were important data to estimate a global merged damage function.

Firstl of all, estimated country population was obtained from the United Nations Statistics Division around 1999. Secondly, the country population data was allocated to the relevant latitude band. If the specific country stretched over the plural latitude band, its population was divided into a respective zone with ratio of the area as a weight. However the locations of main cities were considered for some large countries, USA, Canada, Russia, and Australia. Additionally, some countries located out of the lat.60N-lat.60S range, Iceland and northern part of Norway, Sweden, USA (Alaska), Canada and Russia was handled as located in the lat.60N-lat.50N band. Next, skin color ratio in specific country was decided based on some references such as CIA Fact Book 1999. Finally, the population for a respective skin color type in a specific latitude band was aggregated with these data.

1.4 Global merged damage function

Using the damage function for respective latitude band and population distribution, global merged damage function (GDF) of ozone depletion for skin cancer was calculated.

$$GDF = \Sigma\, DF(X)\, E(X) \qquad (9)$$

Here, DF(X) is the globally merged total increase of skin cancer incidence due to 1 kt of newly emitted specific ODS X [incidence kt^{-1}]. E(X) is emission amount of specific ODS X [kt]. DF(X) of target ODS is shown in **Table 4**.

Table 4: DF(X) of target ODSs [incidence / kt]

ODSs		dTCL(X)/dt coefficients	FC(X)	dEESC(X)/dt coefficients
CFCs	CFC-11	0.081	0.59	0.048
	CFC-12	0.061	0.35	0.022
	CFC-113	0.059	0.44	0.026
Halons	Halon-1211	0.920	0.65	0.597
	Halon-1301	0.996	0.47	0.470
Carbon Tetrachloride		0.096	0.63	0.060
1,1,1-Trichloroethane		0.083	0.64	0.053
HCFCs	HCFC-22	0.043	0.21	0.009
	HCFC-123	0.049	0.65	0.032
	HCFC-124	0.027	0.31	0.008
	HCFC-141b	0.063	0.42	0.027
	HCFC-142b	0.037	0.21	0.008
Methyl Bromide		1.563	0.64	0.996

*dEESC(X)/dt coefficient = FC(X) dTCL(X)/dt coefficient
*dEESC(X)/dt [pptv] = dEESC(X)/dt coeffient Emission(X) [kt]

2 Result and Discussion

We compared our result with the similar estimation reported in some literature. Firstly, the effect of ozone depletion on human health is seen in UNEP (1994) that a sustained 1% decrease of the stratospheric ozone will bring approximately 2% increase of non-melanoma skin cancer incidence. Simi-

lar estimation using the damage function introduced in this study resulted in a 0.7% increase of non-melanoma skin cancer throughout the world. Next, the Eco-indicator 99 (Goedkoop and Spriensma, 2000b) produced the damage factors for ozone layer depletion. And it shows the damage factors of representative ODSs as the disability-adjusted life years (DALYs) [DALYs/kg]. While our result indicates a number of new incidence of skin cancer, some conversion into DALYs based indicator was therefore required to compare. Hofstetter (1998) shows the DALYs of melanoma and other skin cancer, 3.4 and 2.8 [DALYs] without or with age-weighting, respectively. We used the DALYs of Hofstetter (1998) and calculated the DALYs based damage factors for respective ODS [DALYs/kg]. The result is seen in **Table 5** and it was several ten times as small as the Eco-indicator 99 (egalitarian and hierarchic value) except methyl bromide. In the Eco-indicator 99, the damage per kg ODSs are calculated by multiplying the equivalency factor of specific ODS

Table 5: Comparison of DALYs based damage function between our result and Eco-indicator 99

ODSs		Damage of human health [DALYs / kg]			Ratio	
		Our result		EI 99	A/C	B/C
		A	B	C		
CFCs	CFC-11	7.24E-5	5.96E-5	1.05E-3	0.07	0.06
	CFC-12	7.58E-5	6.24E-5	8.63E-4	0.09	0.07
	CFC-113	7.75E-5	6.39E-5	9.48E-4	0.08	0.07
Halons	Halon-1211	1.81E-4	1.49E-4	5.37E-3	0.03	0.03
	Halon-1301	1.06E-3	8.71E-4	1.26E-2	0.08	0.07
Carbon Tetrachloride		6.97E-5	5.74E-5	1.26E-3	0.06	0.05
1,1,1-Trichloroethane		4.91E-6	4.05E-6	1.26E-4	0.04	0.03
HCFCs	HCFC-22	2.91E-6	2.40E-6	4.21E-5	0.07	0.06
	HCFC-123	1.88E-7	1.55E-7			
	HCFC-124	1.12E-6	9.21E-7			
	HCFC-141b	6.43E-6	5.30E-6	1.05E-4	0.06	0.05
	HCFC-142b	4.43E-6	3.65E-6	5.26E-5	0.08	0.07
Methyl Bromide		3.51E-7	2.89E-7	6.74E-4	0.00	0.00

- Damage of human health: Sum of melanoma and non-melanoma skin cancer.
- Our result: Based on the DALYs of skin cancers produced by Hofstetter (1998). A and B are of DALYs without or with age-weighting respectively.
- EI 99: Damage factors shown in the Eco-indicator 99 (egalitarian and hierarchist) (Goedkoop and Spriensma, 2000).

and the damage per kg CFC-11 which is introduced by multiplying the fate factor and the DALYs per % ozone layer depletion. The methodological approach of the Eco-indicator 99 slightly differs from our method.

A case study for a refrigerator was also performed. The inventory data was obtained from the Committee of International Study for Rational Using Methods of Energy (1995) (in Japan). The inventory shows weight content of ODSs as coolant and foaming agent in a refrigerator for old types and alternate types. We assumed that no ODS was collected in the life cycle and all of ODS was emitted into the atmosphere, then we estimated the DALYs based damage factor for old and new type of a refrigerator and compared them. The result is showed in **Table 6**. The estimated DALYs value of for an old refrigerator was 1.27E-5 and 1.05E-5 without or with age-weighting respectively. And same DALYs value for an alternate refrigerator was 9.09E-6 and 7.48E-6. The effect of shifting to less ozone depleting substances for a refrigerator was assessed as reduction to one-fourteenth in DALYs.

3 Conclusion and Future Work

The main objective of our study was to quantify the relationship of human health impact to the ODS emission as a first step. We could introduce damage functions of ozone depletion for skin cancer incidence and it is expected that the result of our study will contribute to the evaluation procedure on the ozone depletion problem in LCIA. However, there were many assumptions and simplifications in the estimation. Nevertheless, it must be said that methodological improvement must be indispensable with newest knowledge when it is available. Additionally, the uncertainty of the damage function should be estimated.

As one of the important problem, the dimension of 'time' was excluded in the damage function and simplified as a total increase of skin cancer incidence during newly emitted specific ODS existing in the atmosphere. In this case, two types of ODSs which have different characteristics, one has short life-times but strong ozone depleting activity and another has inverse property, are possible to be evaluated as the same impact. Generally, an abatement measure will take precedence on the ODSs that have acute depleting activity.

Table 6: A case study of the alternation effect for refrigerators

Term	Unit	Old type of refrigerator			Alternate type of refrigerator		
		Coolant	Foaming agent	Total	Coolant	Foaming agent	Total
Material	-	CFC-12	CFC-11	-	HFC-134a	HCFC-141b	-
Weight	kg / refrigerator	0.20	0.84	-	0.18	0.69	-
Global merged damage function	incidence / kt	22.29	21.29	-	0	1.89	-
Increase number of skin cancer	incidence / refrigerator	4.46E-6	1.79E-5	2.23E-5	0	1.31E-6	1.31E-6
DALYs damage A	DALYs / refrigerator	1.52E-5	6.08E-5	7.59E-5	0	4.44E-6	4.44E-6
DALYs damage B	DALYs / refrigerator	1.25E-5	5.01E-5	6.25E-5	0	3.66E-6	3.66E-6

- Global merged damage function: The estimation results in our study.
- DALYs damage A and B: Products of the increase number of skin cancer and the DALYs of skin cancers produced by Hofstetter (1998). A and B are of DALYs without or with age-weighting respectively, 3.4 and 2.8 DALYs.

Therefore, it is desirable that a time oriented estimation method will be developed. In relation to the time problem, skin cancer incidence will be occurred by long-term exposure to UV-B. Then one question will arise concerning which human will acquire skin cancer under increased UV-B due to ODS emission. In our study, we only modeled the relationship between present UV-B amount and skin cancer incidence rate and substituted UV-B amount after new emission of ODSs to the regression. On the estimation method, the ODS life-time was taken into consideration as a coefficient by integrating its life-time, however, there was an audacious assumption that skin cancer incidence rates had linear proportions to UV-B amount.

As future work, not only uncertainty analysis and methodological improvement mentioned above, but also damage functions of other endpoints are required, such as human health: e.g. cataract, ecosystem: e.g. land and marine primary production, and agriculture: e.g. crop production.

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